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New Constraints on Dark Energy

COSMOLOGICAL COSTANT vs “Something else”

$$\Omega_\Lambda \equiv const$$
$$p = -\rho$$
$$\delta\rho_\Lambda = 0$$

$$\Omega_X \equiv f(z)$$
$$p = w(z)\rho$$
$$\delta\rho_X \neq 0$$

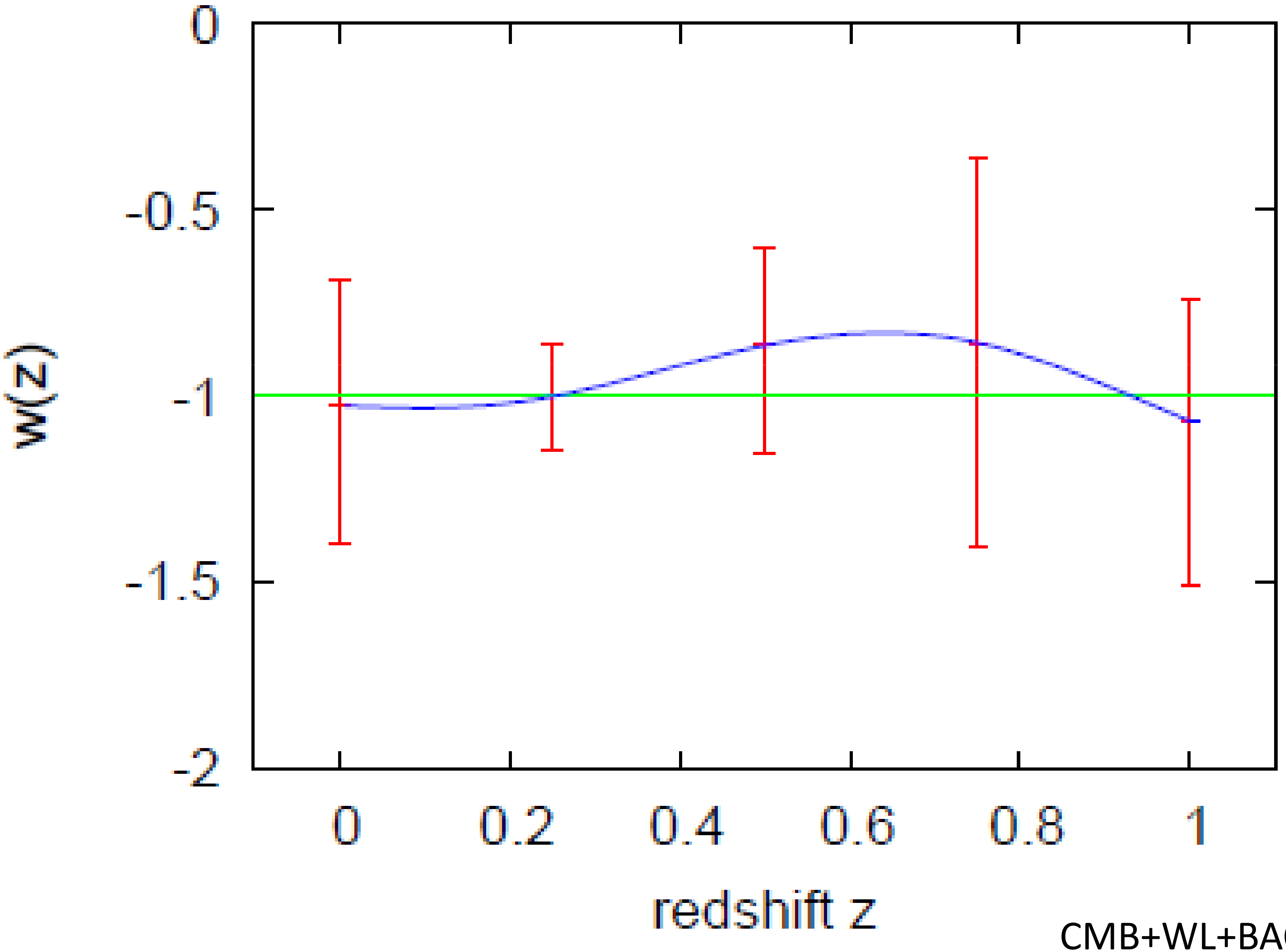
Dark Energy- a recent analysis for w(z)

- We sample w(z) in 5 redshift bins up to z=1:

$$w(z) = \begin{cases} w(z=1), & z > 1; \\ w_i, & z \leq z_{max}, z \in \{z_i\}; \\ \text{spline}, & z \leq z_{max}, z \notin \{z_i\}. \end{cases}$$

- We use CMB (WMAP5,QUAD, ACBAR) data, BAO DR7, Weak Lensing from CFHFTLS, ISW data, Supernovae from UNION and CONSTITUTION datasets.

Serra, Cooray, Holtz, Melchiorri, Pandolfi, Sarkar, Phys.Rev.D80:121302,2009



CMB+WL+BAO+UNION+ISW

Serra, Cooray, Holtz, Melchiorri, Pandolfi, Sarkar,
Phys.Rev.D80:121302,2009

Parameter	WMAP+UNION+BAO	WMAP+Constitution+BAO	all dataset	future datasets
$\Omega_b h^2$	0.02281 ± 0.00057	0.02278 ± 0.00058	0.02304 ± 0.00056	0.02270 ± 0.00015
$\Omega_c h^2$	0.1128 ± 0.0059	0.1144 ± 0.0060	0.1127 ± 0.0018	0.1100 ± 0.0012
Ω_Λ	0.728 ± 0.018	0.715 ± 0.017	0.728 ± 0.016	0.751 ± 0.008
n_s	0.964 ± 0.014	0.963 ± 0.014	0.971 ± 0.014	0.962 ± 0.004
τ	0.085 ± 0.017	0.084 ± 0.016	0.088 ± 0.017	0.084 ± 0.05
Δ^2_R	$(2.40 \pm 0.10) \cdot 10^{-9}$	$(2.40 \pm 0.10) \cdot 10^{-9}$	$(2.40 \pm 0.10) \cdot 10^{-9}$	$(2.40 \pm 0.10) \cdot 10^{-9}$
$w(z = 1.7)$	$--$	$--$	$--$	$-1.55^{+0.46}_{-0.44}$
$w(z = 1)$	$-1.72^{+0.73}_{-0.81}$	$-1.68^{+0.73}_{-0.85}$	$-1.07^{+0.21}_{-0.20}$	-1.03 ± 0.10
$w(z = 0.75)$	$-0.71^{+0.44}_{-0.47}$	$-0.47^{+0.34}_{-0.33}$	$-0.86^{+0.025}_{-0.26}$	-0.98 ± 0.08
$w(z = 0.5)$	$-0.65^{+0.29}_{-0.30}$	$-1.06^{+0.41}_{-0.40}$	-0.86 ± 0.14	-1.00 ± 0.05
$w(z = 0.25)$	-1.05 ± 0.10	-1.04 ± 0.07	-1.00 ± 0.07	-1.00 ± 0.02
$w(z = 0)$	-0.97 ± 0.22	-0.86 ± 0.13	$-1.02^{+0.17}_{-0.18}$	-0.99 ± 0.05
σ_8	0.814 ± 0.055	0.815 ± 0.057	0.810 ± 0.024	0.811 ± 0.012
Ω_m	0.272 ± 0.018	0.285 ± 0.017	0.272 ± 0.016	0.249 ± 0.008
H_0	70.7 ± 2.0	69.4 ± 1.7	70.8 ± 2.0	73.1 ± 1.0
z_{reion}	10.8 ± 1.4	10.8 ± 1.4	11.0 ± 1.5	10.7 ± 0.4
t_0	13.65 ± 0.14	13.67 ± 0.15	13.67 ± 0.13	13.60 ± 0.06

No evidence from current data for deviations from a cosmological constant

Serra, Cooray, Holtz, Melchiorri, Pandolfi, Sarkar, Phys.Rev.D80:121302,2009

Modifying Gravity at Large Scales

Inside the Solar-system, GR is tested with a post-Newtonian parameters using the Eddington-Robertson-Schiff metric (with α=1):

$$ds^2 = -\left[1 - 2\alpha\frac{GM}{r} + 2(\beta - \alpha\gamma)\left(\frac{GM}{r}\right)^2 + \ldots\right] dt^2 + \left[1 + 2\gamma\frac{GM}{r} + \ldots\right] dr^2 + r^2 d\Omega^2 \qquad (1)$$

In GR, $\beta=\gamma=1$. Lunar-ranging and time-delay with spacecraft give

$$\gamma - 1 = 2.1\,(\pm 2.3) \times 10^{-5} \qquad \beta - 1 = 1.2\,(\pm 1.1) \times 10^{-4}\,;$$

In similar spirit, GR can be tested at cosmological length scales for cosmological perturbations *(Bertschinger 2006; Caldwell, Cooray & Melchiorri 2007)*

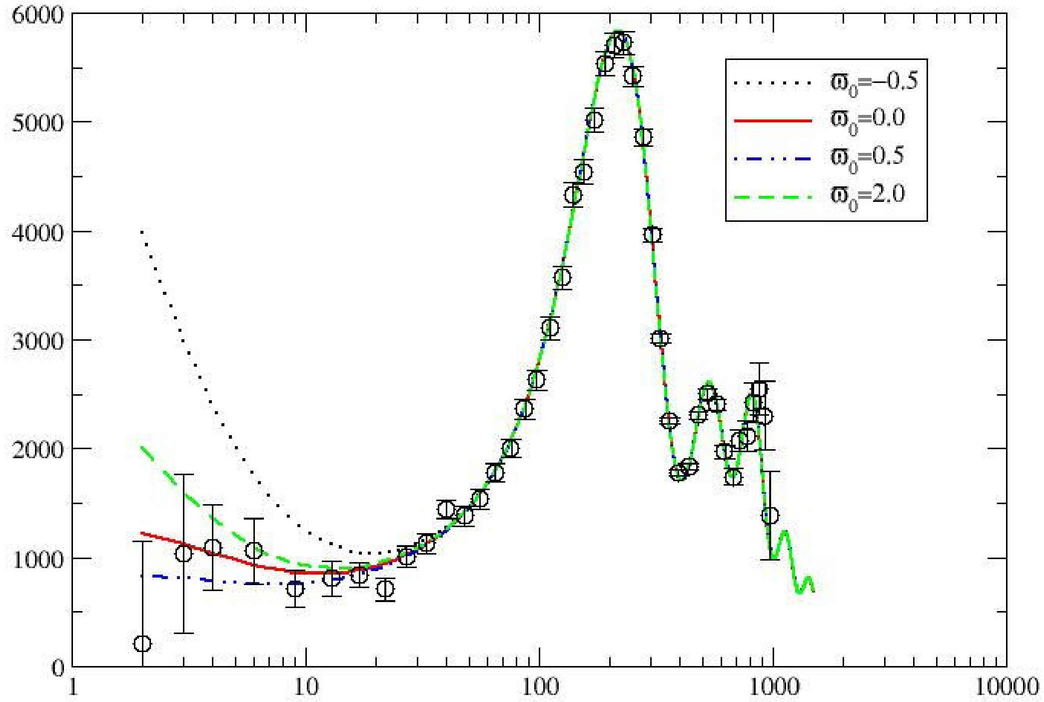
$$ds^2 = a^2\left[-(1 + 2\psi)\, d\tau^2 + (1 - 2\phi)\, d\vec{x}^2\right] \qquad \psi = (1 + \varpi)\phi,$$

$$k^2(\phi - \psi) = 12\pi G a^2(\rho + p)\sigma|_{\gamma,\nu} - \varpi\, k^2\phi.$$

At late-times today in GR, ϖ=0

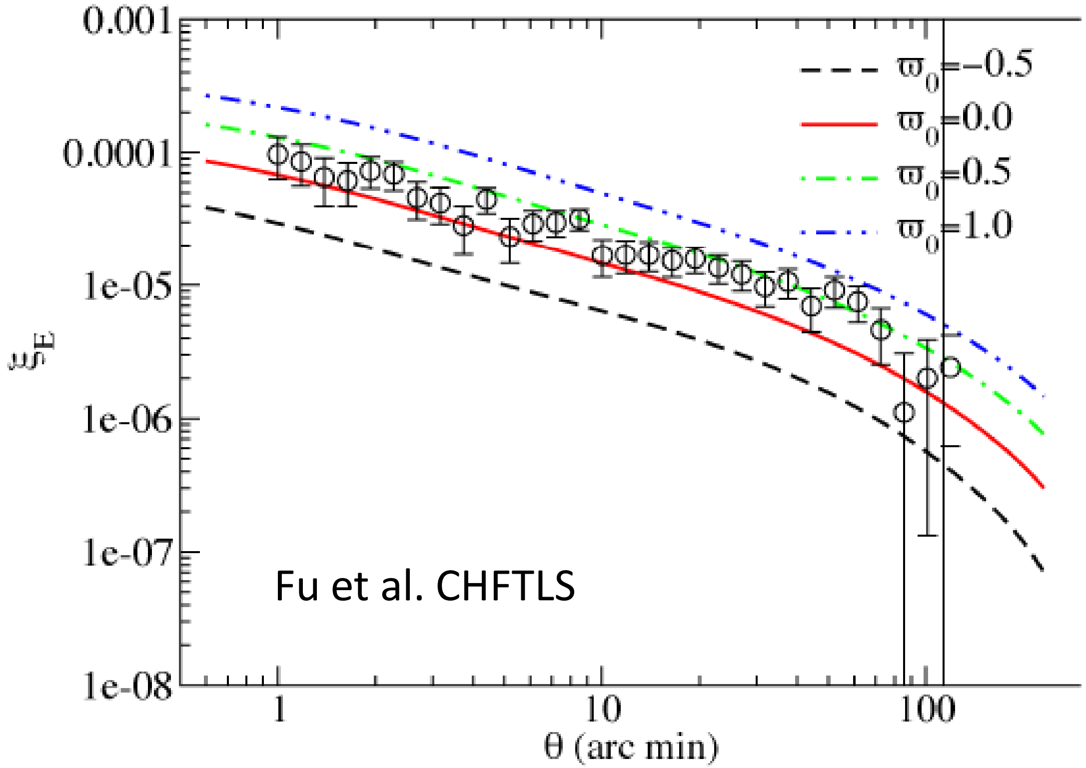
ϖ is time-dependent; CCM choice:

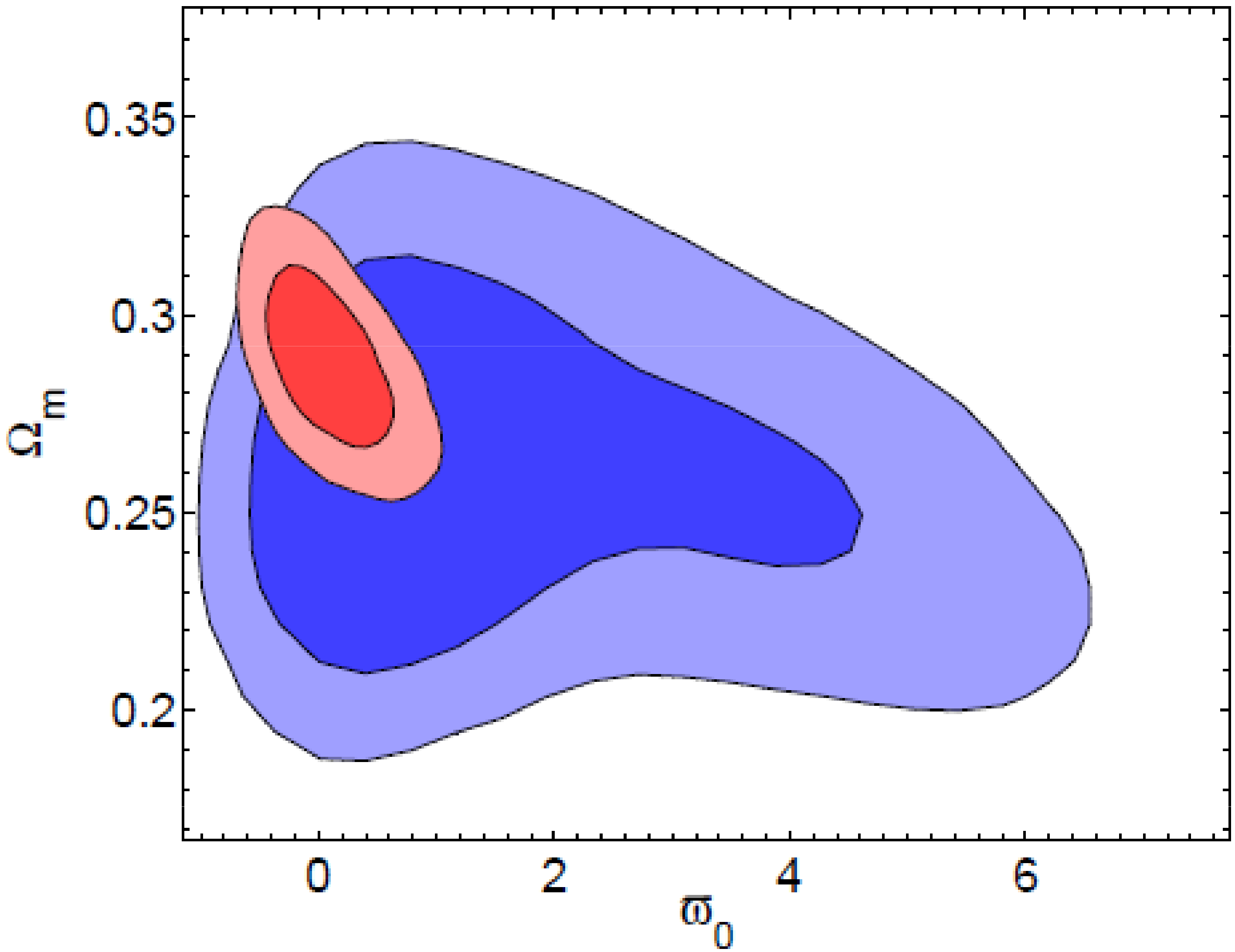
$$\varpi = \varpi_0\frac{\rho_{DE}}{\rho_M} = \varpi_0\frac{\Omega_{DE}}{\Omega_M}(1 + z)^{-3}.$$



CMB modifications are essentially changes to the ISW

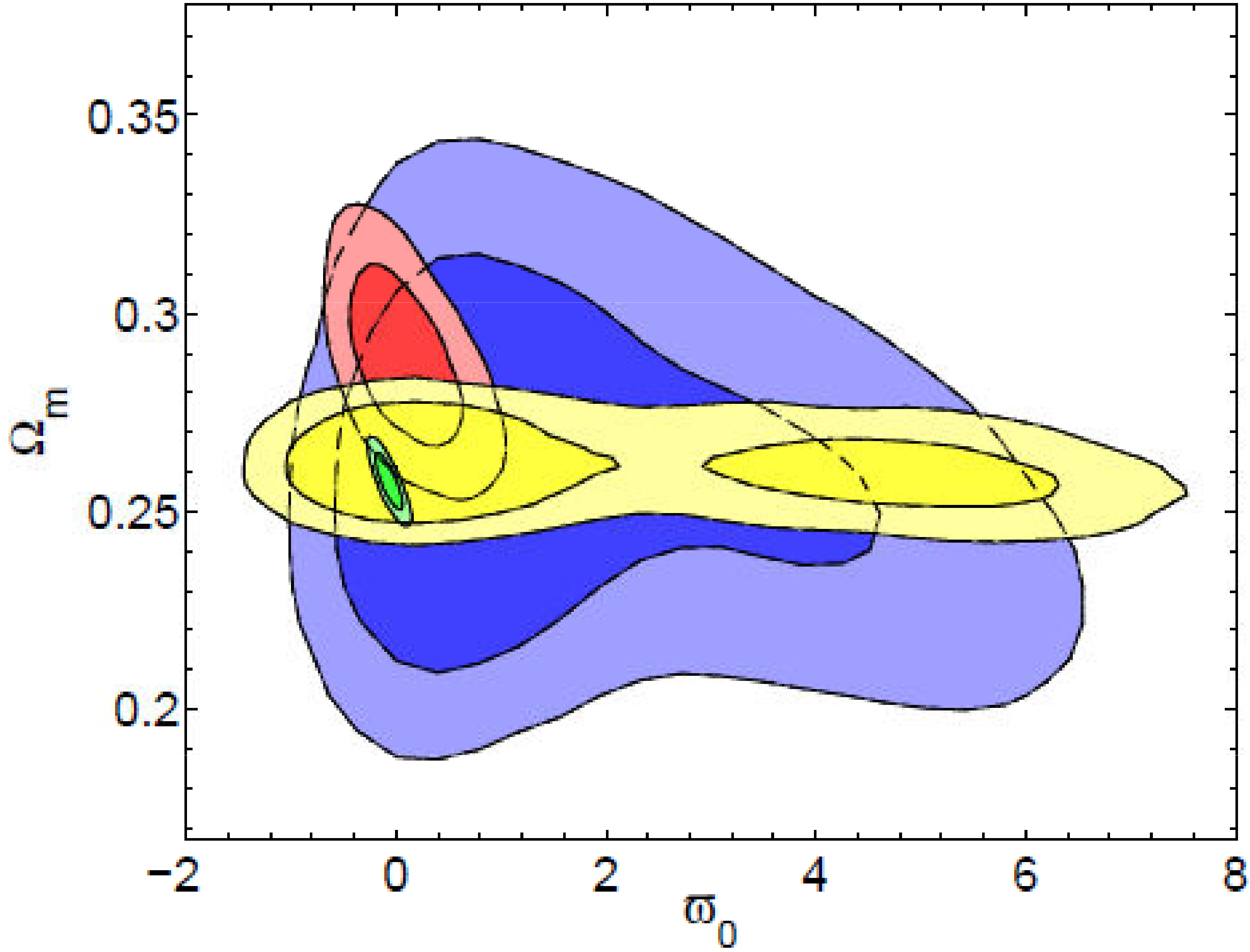
Weak lensing modifications are a combination of $\phi+\psi$ and growth function.





Blue: WMAP5 data only
Red: Combinining all current data (CMB+WL+SNIa)

Daniel, Caldwell, Cooray, Melchiorri, Serra, Phys.Rev.D80:023532,2009



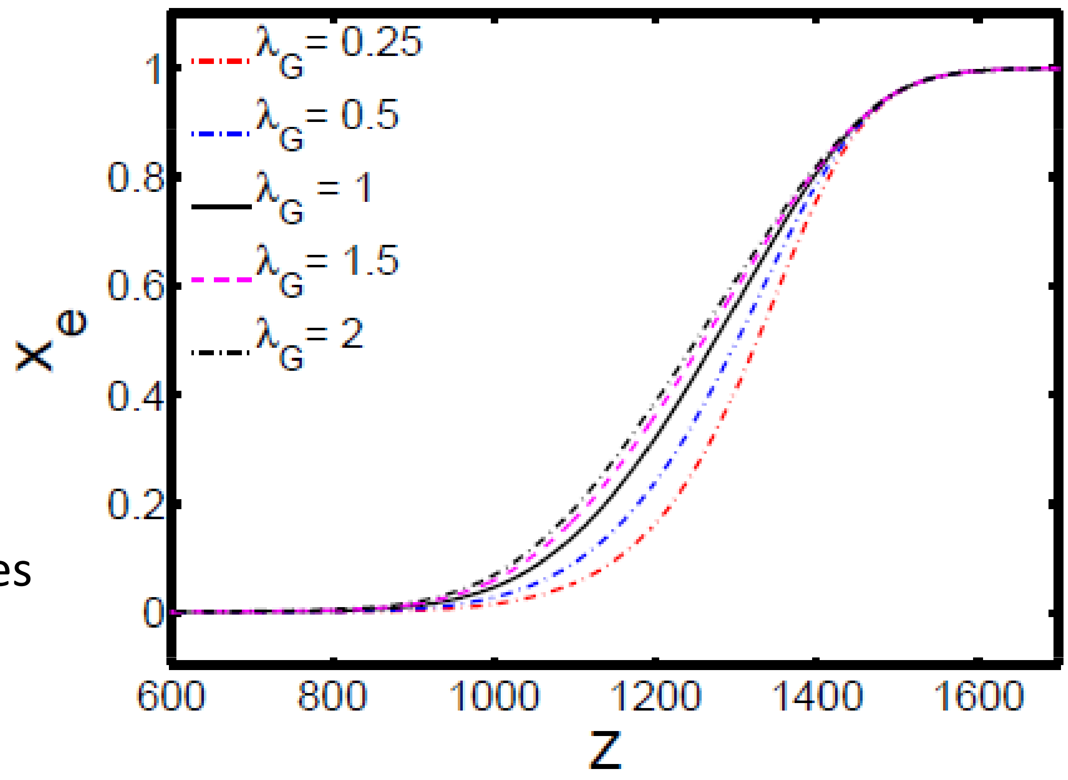
Daniel, Caldwell, Cooray, Melchiorri, Serra, Phys.Rev.D80:023532,2009

Variations in Newton's Gravitational Constant G

$$G \rightarrow \lambda_G^2 G$$

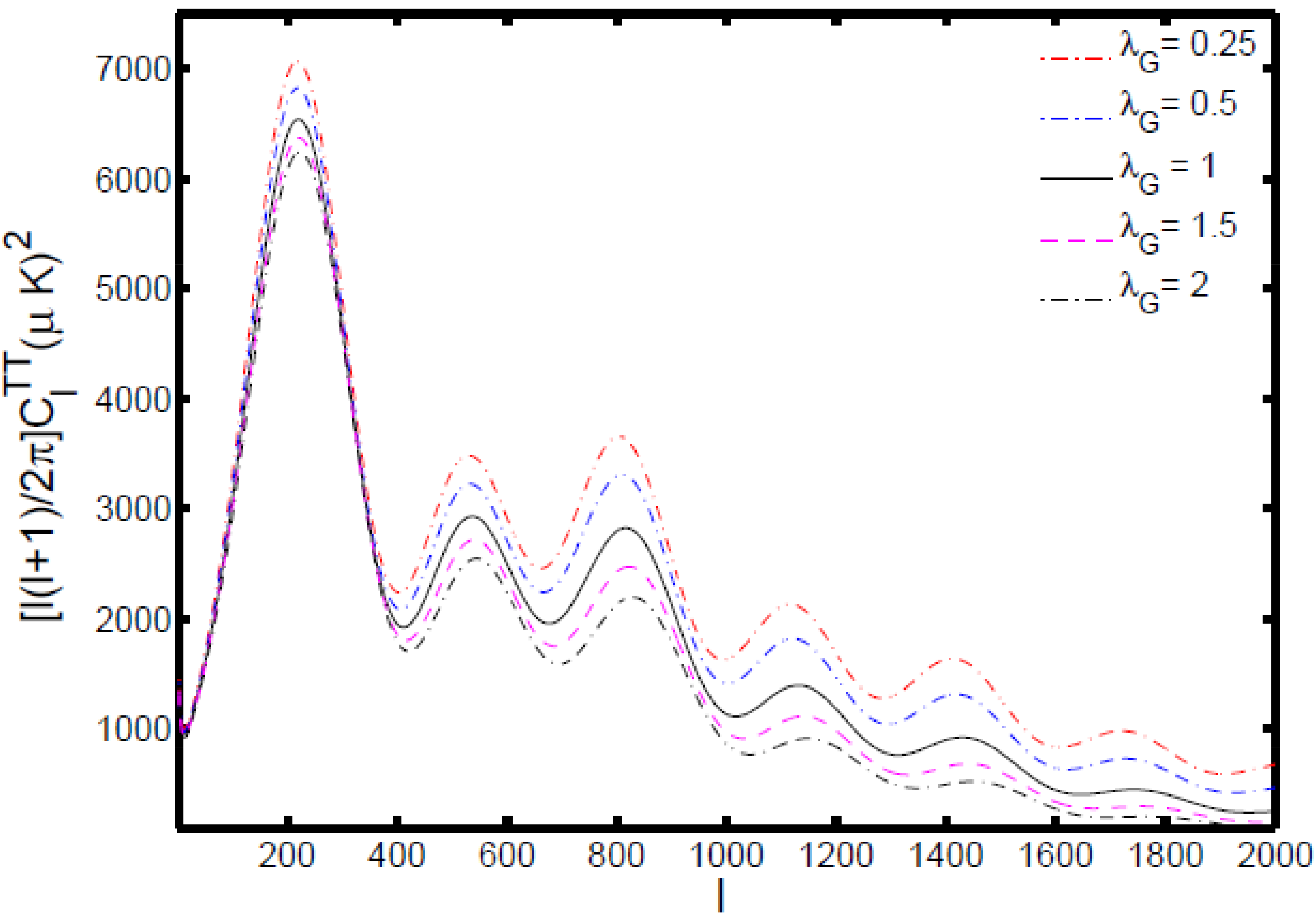
Expressing the evolution of perturbations in Fourier Space a variation of G simply rescales the wavenumbers:

$$k' = k/\lambda_G$$



However, recombination introduces a preferred timescale. Changing G has the effect of changing the Recombination epoch.

Galli, Melchiorri, Smoot, Zahn, Phys.Rev.D80:023508,2009



λ_G= 0.25
λ_G= 0.5
λ_G = 1
λ_G= 1.5
λ_G= 2
$[l(l+1)/2\pi]C_l^{TT}(\mu K)^2$
7000
6000
5000
4000
3000
2000
1000
200
400
600
800
1000
1200
1400
1600
1800
2000
l

Experiment	Constraints on λ_G at 68% c.l.
WMAP	1.01 ± 0.16
WMAP+POL	0.97 ± 0.13
WMAP+ACBAR	1.03 ± 0.11
WMAP+BBN	0.98 ± 0.03
PLANCK	1.01 ± 0.015
CVL	1.002 ± 0.004

Experiment	Channel	FWHM	$\Delta T/T$	$\Delta P/T$
Planck	70	14'	4.7	6.7
$f_{sky} = 0.85$	100	10'	2.5	4.0
	143	7.1'	2.2	4.2
ACT	150	1.4'	14.6	20.4
$f_{sky} = 0.19$				
CMBPOL	150	5.6'	0.037	0.052
$f_{sky} = 0.72$				

Parameter	Planck	Planck+ACT	CMBPOL
$\Delta(\Omega_b h^2)$	0.00013	0.000078	0.000034
$\Delta(\Omega_c h^2)$	0.0010	0.00064	0.00027
$\Delta(\theta_s)$	0.00026	0.00016	0.000052
$\Delta(\tau)$	0.0042	0.0034	0.0022
$\Delta(n_s)$	0.0031	0.0021	0.0014
$\Delta(log[10^{10} As])$	0.013	0.0086	0.0055

Parameter	Planck	Planck+ACT	CMBPOL
$\Delta(\Omega_b h^2)$	0.00014	0.000081	0.000033
$\Delta(\Omega_c h^2)$	0.0017	0.0010	0.00071
$\Delta(\theta_S)$	0.00028	0.00016	0.000062
$\Delta(\tau)$	0.0042	0.0034	0.0023
$\Delta(n_S)$	0.0034	0.0022	0.0016
$\Delta(\log[10^{10} A_S])$	0.013	0.0094	0.0065
$\Delta(\sum m_\nu)$	< 0.29	< 0.15	< 0.10

TABLE III: 1 σ error. the upper limits on $\sum m_\nu$ are at 95% c.l.

Parameter	Planck	Planck+ACT	CMBPOL
$\Delta(\Omega_b h^2)$	0.00019	0.00013	0.000051
$\Delta(\Omega_c h^2)$	0.0010	0.00065	0.00027
$\Delta(\theta_S)$	0.00046	0.00026	0.00010
$\Delta(\tau)$	0.0043	0.0035	0.0023
$\Delta(n_S)$	0.0063	0.0043	0.0025
$\Delta(\log[10^{10} A_S])$	0.013	0.013	0.0079
$\Delta(Y_p)$	0.010	0.0061	0.00029

TABLE V: 1 sigma error. the upper limits on Y_p are at 95% c.l.

Parameter	Planck	Planck+ACT	CMBPOL
$\Delta(\Omega_b h^2)$	0.00013	0.000080	0.000031
$\Delta(\Omega_c h^2)$	0.0011	0.00072	0.00037
$\Delta(\theta_s)$	0.00026	0.00016	0.000053
$\Delta(\tau)$	0.0040	0.0033	0.0022
$\Delta(n_s)$	0.0032	0.0022	0.0016
$\Delta(log[10^{10} As])$	0.013	0.0098	0.0067
$\Delta(w)$	0.2	0.15	0.080

TABLE VI: 68% c.l. errors on cosmological parameters from future surveys.